Two-particle correlations and the small-x gluon four-point function

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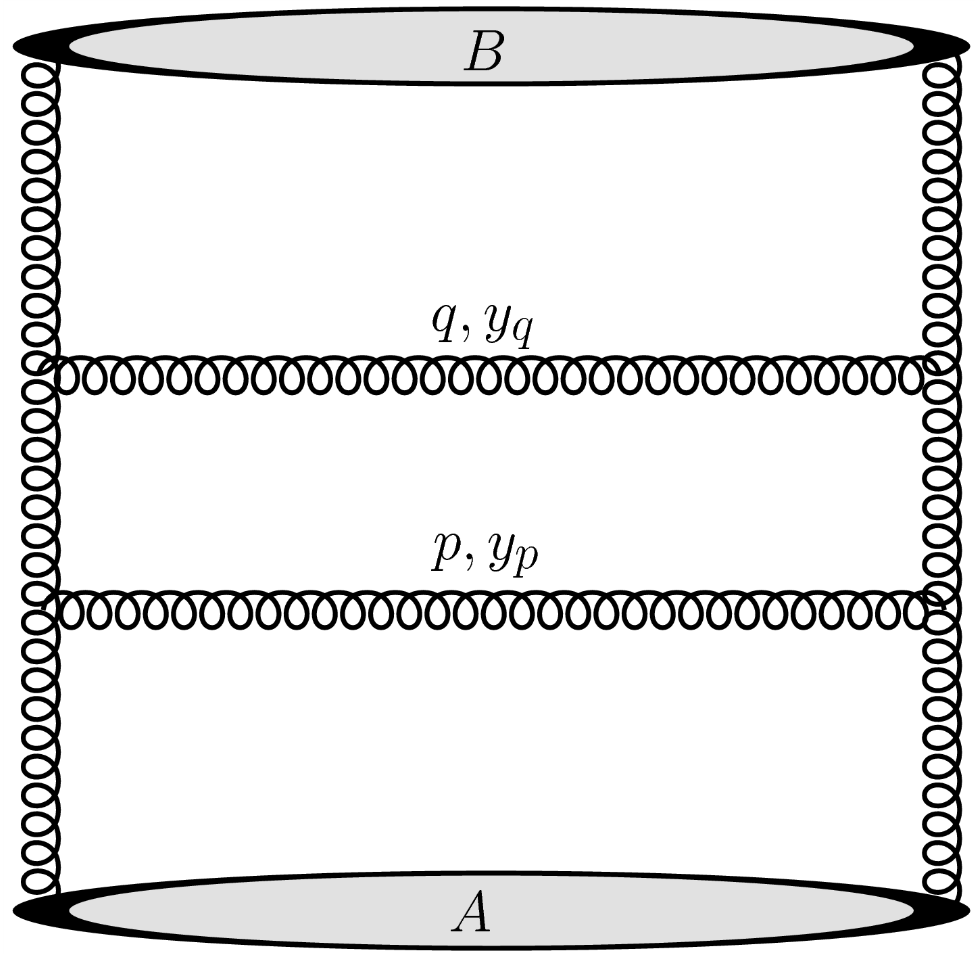
A.D., Jamal Jalilian-Marian: arXiv:1001.4820

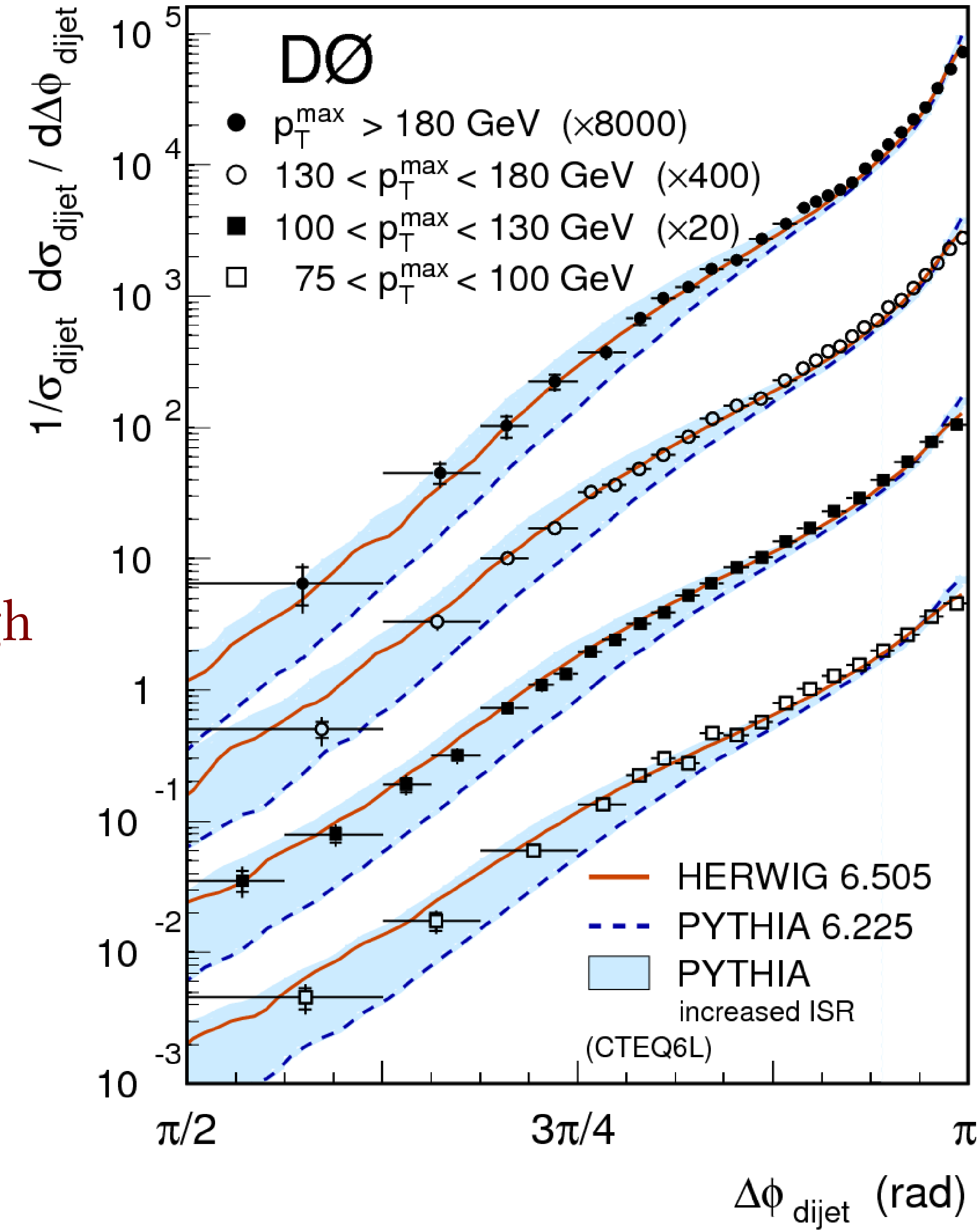
(Correlated) two-particle production: the DGLAP way

~ δ(p+q) (at leading order, back-to-back dijet)



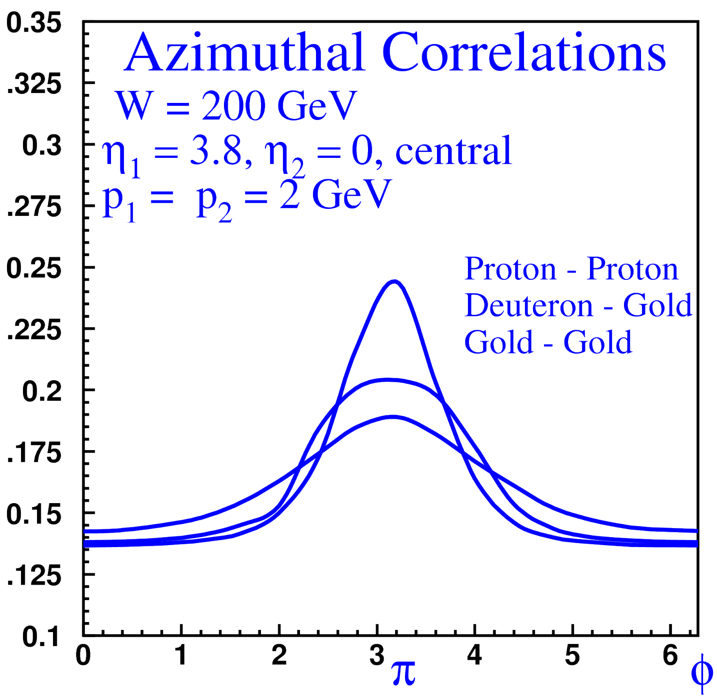
Angular correlation at high p_T ($p\bar{p}$ @ TEVATRON) :

- DGLAP$_{LO}$-ish $\sim \delta(p+q)$

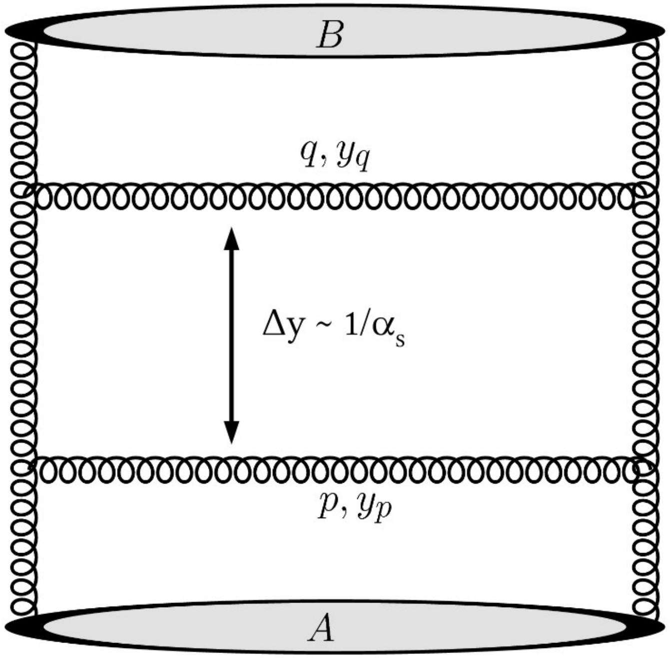


(Correlated) two-particle production: BFKL kinematics, Mueller-Navelet jets

- smears out the back-to-back dijet

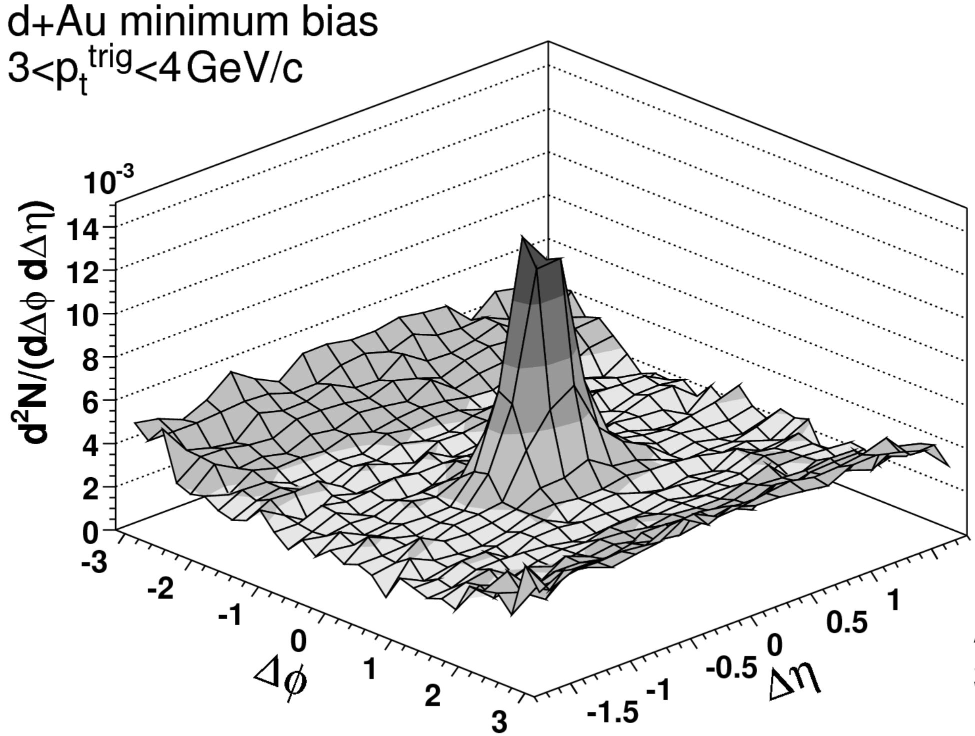


Kharzeev, Levin, McLerran: hep-ph/0403271

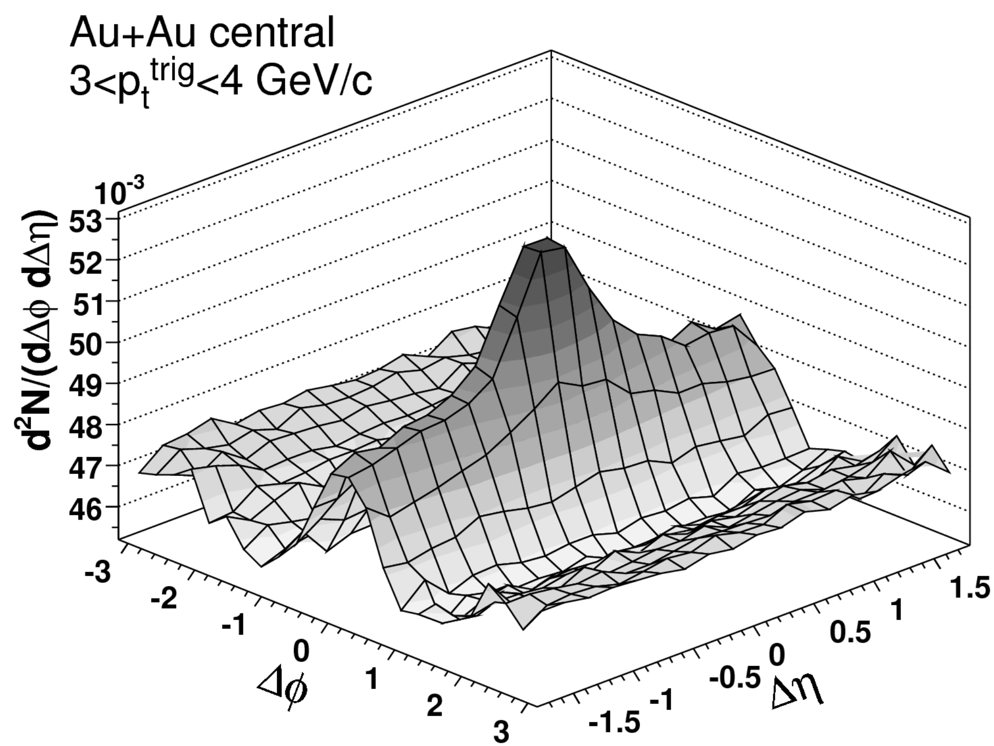


However, this talk is NOT about “back to back” correlations …

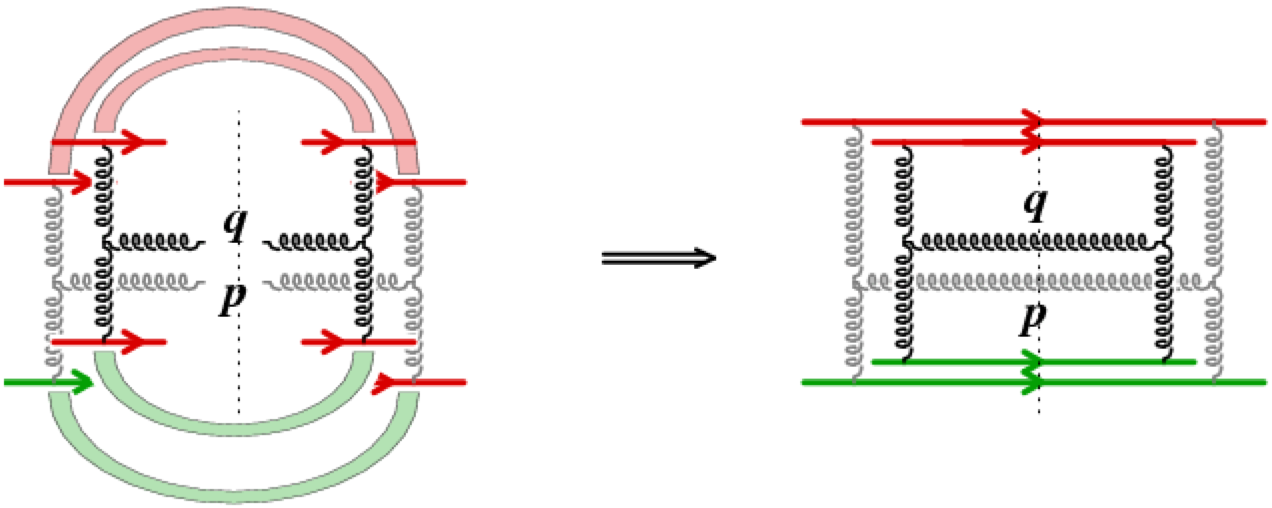
Near-side correlations, Φ<1 (the "ridge")



STAR (arXiv:0909.0191)



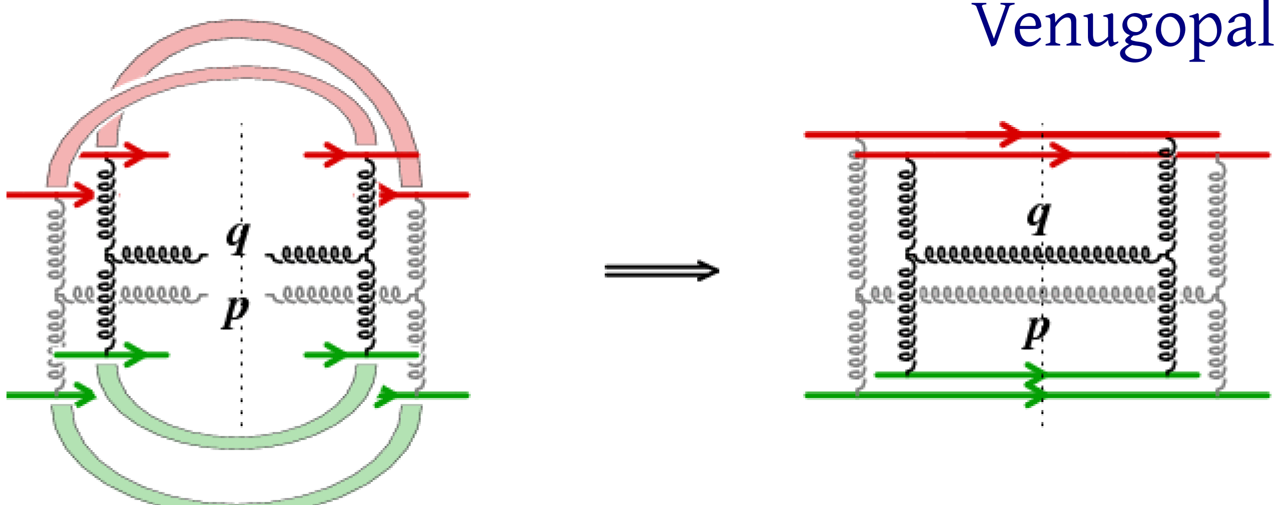
Independent production of two gluons:

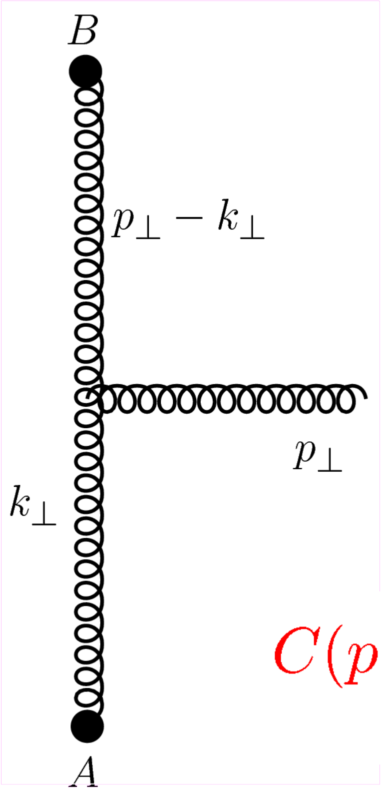


PYTHIA: “independent multi-parton inter-actions”

Correlated two-gluon production:

A.D., Gelis, McLerran, Venugopalan: 0804.3858





$$\mathcal{M}^a_\lambda = p^2 A^{\mu,a}(p)\,\epsilon^\lambda_\mu(p)$$

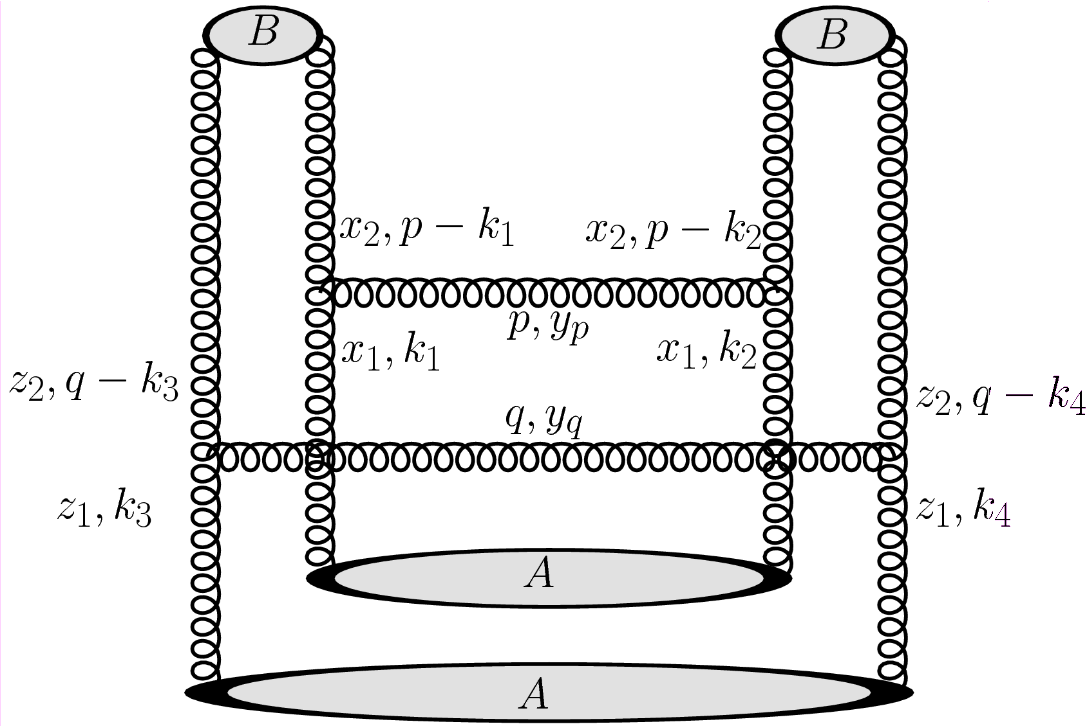
$$p^2 A^{\mu,a}(p) = -i f^{abc}\frac{g^3}{2}\int \frac{d^2k_\perp}{(2\pi)^2} L^\mu(p_\perp,k_\perp)\frac{\rho^a_A(k_\perp)}{k_\perp^2}\frac{\rho^b_B(p_\perp-k_\perp)}{(p_\perp-k_\perp)^2}$$

$$C(p,q) \sim \sum_{a,a';\lambda,\lambda'}\left(\left\langle|\mathcal{M}^{aa'}_{\lambda\lambda'}(p,q)|^2\right\rangle - \left\langle|\mathcal{M}^a_\lambda(p)|^2\right\rangle\left\langle|\mathcal{M}^{a'}_{\lambda'}(q)|^2\right\rangle\right)$$

two-point function:

$$\langle\rho^{*a}(k)\,\rho^b(q)\rangle(x) \sim \frac{1}{g^2}\frac{\delta^{ab}}{N_c^2-1}\,\delta(k-q)\,\Phi(x,k^2)$$

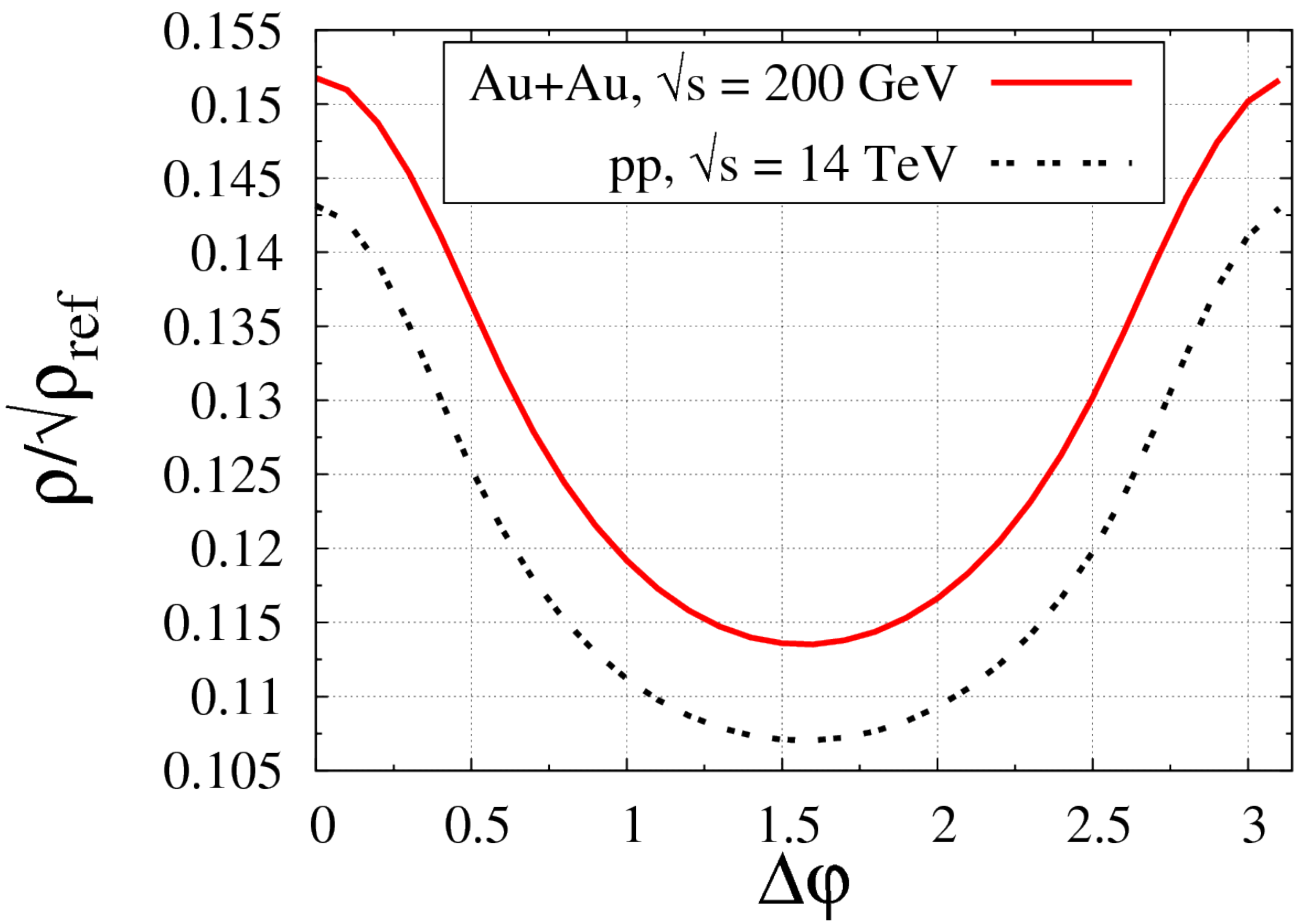
unintegr. gluon distrib.



$$
\begin{aligned}
C(p,q) \quad &= \quad 16(2\pi)^2\alpha_s^2\, S_\perp \frac{N^2}{(N^2-1)^3}\frac{1}{p_\perp^2}\frac{1}{q_\perp^2} \\
&\int d^2k_\perp \frac{\Phi_A(x_1,(p_\perp+k_\perp)^2)}{(p_\perp+k_\perp)^2}\frac{\Phi_A(x_1,(q_\perp-k_\perp)^2)}{(q_\perp-k_\perp)^2}\frac{\Phi_B^2(x_2,k_\perp^2)}{k_\perp^4}
\end{aligned}
$$

Depends on angle $\angle(p_\perp,q_\perp)$, not flat in ϕ !

RHIC(Au+Au) versus LHC(pp) :

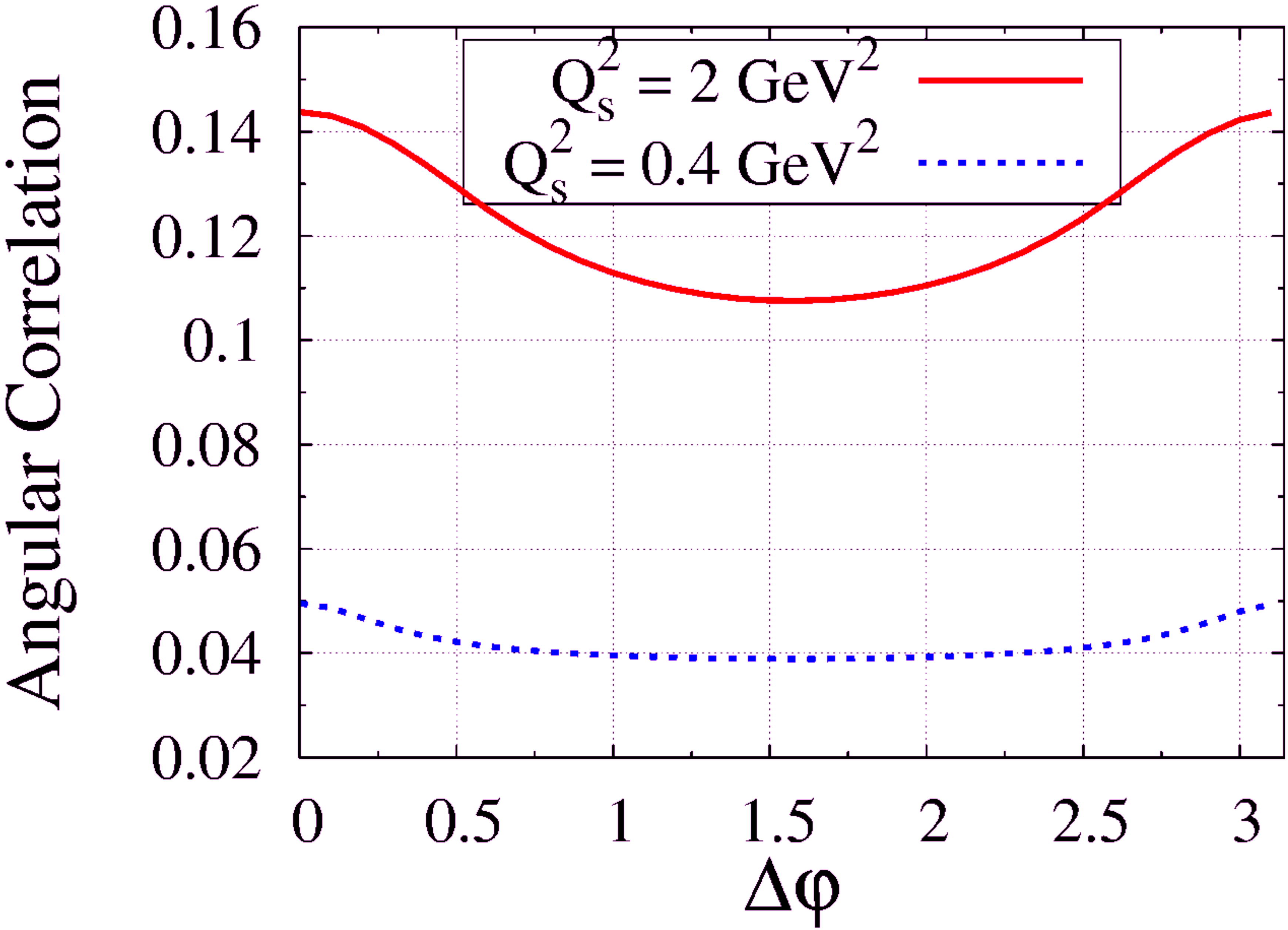


ridge in pp @ LHC ?!

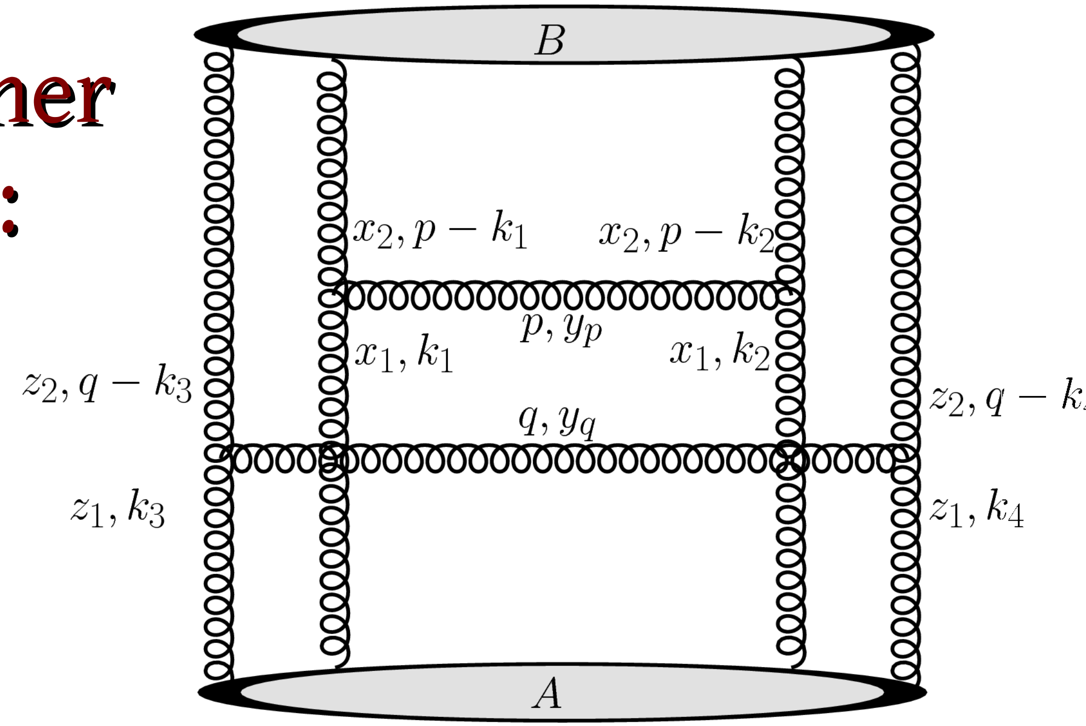
AA versus pp :

$p_\perp$ = 5 GeV, $y_p = y_q = 0$

$q_\perp$ = 4 GeV



however, we should rather compute THIS diagram:



$$C(p_\perp, q_\perp) = \quad \frac{g^{12}}{64(2\pi)^6} \left(f_{abc} f_{a'\bar{b}\bar{c}} f_{a\hat{b}\hat{c}} f_{a'\tilde{b}\tilde{c}}\right) \int \prod_{i=1}^{4} \frac{d^2 k_{i\perp}}{(2\pi)^2 k_{i\perp}^2}$$

$$\times \frac{L_\mu(p_\perp, k_{1\perp}) L^\mu(p_\perp, k_{2\perp})}{(p_\perp - k_{1\perp})^2 (p_\perp - k_{2\perp})^2} \frac{L_\nu(q_\perp, k_{3\perp}) L^\nu(q_\perp, k_{4\perp})}{(q_\perp - k_{3\perp})^2 (q_\perp - k_{4\perp})^2}$$

$$\times \left\langle {\rho^*}_1^{\hat{b}}(k_{2\perp}) {\rho^*}_1^{\tilde{b}}(k_{4\perp}) {\rho_1}^{b}(k_{1\perp}) {\rho_1}^{\bar{b}}(k_{3\perp}) \right\rangle$$

$$\times \left\langle {\rho^*}_2^{\hat{c}}(p_\perp - k_{2\perp}) {\rho^*}_2^{\tilde{c}}(q_\perp - k_{4\perp}) {\rho_2}^{c}(p_\perp - k_{1\perp}) {\rho_2}^{\bar{c}}(q_\perp - k_{3\perp}) \right\rangle$$

Gaussian approximation (factorization of $\langle\rho^4\rangle \sim \langle\rho^2\rangle^2$)

$$\begin{aligned}\left\langle\rho^a\rho^b\rho^c\rho^d\right\rangle &= \delta^{ab}\delta^{cd}\left\langle\rho^2\right\rangle^2+\delta^{ac}\delta^{bd}\left\langle\rho^2\right\rangle^2+\delta^{ad}\delta^{bc}\left\langle\rho^2\right\rangle^2\\ &\quad +\mathcal{O}\left(\frac{1}{N_c}\right)\end{aligned}$$

$\langle\rho^2\rangle$ can be obtained from BFKL or BK eqn. (standard unintegrated gluon distrib.)

$$\begin{aligned}\partial_Y\left\langle\rho^a\rho^b\rho^c\rho^d\right\rangle &= \delta^{ab}\delta^{cd}\mathcal{Z}+\delta^{ac}\delta^{bd}\mathcal{Z}+\delta^{ad}\delta^{bc}\mathcal{Z}\\ \mathcal{Z} &= \left\langle\rho^2\right\rangle\ \mathcal{K}\otimes\left\langle\rho^2\right\rangle\end{aligned}$$

BFKL kernel

Complete B-JIMWLK four-point function: (no Gaussian approx.)

$$
\begin{aligned}
\frac{d}{dY}\langle \alpha_r^a \alpha_{\bar r}^b \alpha_s^c \alpha_{\bar s}^d \rangle \quad = \\
& \frac{g^2 N_c}{(2\pi)^3}\int d^2z \left\langle \frac{\alpha_z^a \alpha_{\bar r}^b \alpha_s^c \alpha_{\bar s}^d}{(r-z)^2} + \frac{\alpha_r^a \alpha_z^b \alpha_s^c \alpha_{\bar s}^d}{(\bar r-z)^2} + \frac{\alpha_r^a \alpha_{\bar r}^b \alpha_z^c \alpha_{\bar s}^d}{(s-z)^2} + \frac{\alpha_r^a \alpha_{\bar r}^b \alpha_s^c \alpha_z^d}{(\bar s-z)^2} - 4\frac{\alpha_r^a \alpha_{\bar r}^b \alpha_s^c \alpha_{\bar s}^d}{z^2} \right\rangle \\
& + \frac{g^2}{\pi}\int \frac{d^2z}{(2\pi)^2} \left\langle f^{e\kappa a} f^{f\kappa b} \frac{(r-z)\cdot(\bar r-z)}{(r-z)^2(\bar r-z)^2} \left[\alpha_r^e \alpha_{\bar r}^f - \alpha_r^e \alpha_z^f - \alpha_z^e \alpha_{\bar r}^f + \alpha_z^e \alpha_z^f\right] \alpha_s^c \alpha_{\bar s}^d \right. \\
& \qquad + f^{e\kappa a} f^{f\kappa c} \frac{(r-z)\cdot(s-z)}{(r-z)^2(s-z)^2} \left[\alpha_r^e \alpha_s^f - \alpha_r^e \alpha_z^f - \alpha_z^e \alpha_s^f + \alpha_z^e \alpha_z^f\right] \alpha_{\bar r}^b \alpha_{\bar s}^d \\
& \qquad + f^{e\kappa a} f^{f\kappa d} \frac{(r-z)\cdot(\bar s-z)}{(r-z)^2(\bar s-z)^2} \left[\alpha_r^e \alpha_{\bar s}^f - \alpha_r^e \alpha_z^f - \alpha_z^e \alpha_{\bar s}^f + \alpha_z^e \alpha_z^f\right] \alpha_{\bar r}^b \alpha_s^c \\
& \qquad + f^{e\kappa b} f^{f\kappa c} \frac{(\bar r-z)\cdot(s-z)}{(\bar r-z)^2(s-z)^2} \left[\alpha_{\bar r}^e \alpha_s^f - \alpha_{\bar r}^e \alpha_z^f - \alpha_z^e \alpha_s^f + \alpha_z^e \alpha_z^f\right] \alpha_r^a \alpha_{\bar s}^d \\
& \qquad + f^{e\kappa b} f^{f\kappa d} \frac{(\bar r-z)\cdot(\bar s-z)}{(\bar r-z)^2(\bar s-z)^2} \left[\alpha_{\bar r}^e \alpha_{\bar s}^f - \alpha_{\bar r}^e \alpha_z^f - \alpha_z^e \alpha_{\bar s}^f + \alpha_z^e \alpha_z^f\right] \alpha_r^a \alpha_s^c \\
& \qquad \left. + f^{e\kappa c} f^{f\kappa d} \frac{(s-z)\cdot(\bar s-z)}{(s-z)^2(\bar s-z)^2} \left[\alpha_s^e \alpha_{\bar s}^f - \alpha_s^e \alpha_z^f - \alpha_z^e \alpha_{\bar s}^f + \alpha_z^e \alpha_z^f\right] \alpha_r^a \alpha_{\bar r}^b \right\rangle .
\end{aligned}
$$

$$A^\mu(x^+, r) \equiv \delta^{\mu-}\alpha(x^+, r) = -g\,\delta^{\mu-}\delta(x^+)\frac{1}{\nabla_\perp^2}\rho(x^+, r) \qquad k^2\alpha(k) = g\rho(k)$$

however, "subleading-Nc" piece contributes at the same order to C(p,q)

Complete Balitsky/JIMWLK four-point function: (in Gaussian approximation)

$$\left\langle \rho^a \rho^b \rho^c \rho^d \right\rangle \;=\; \delta^{ab}\delta^{cd}\left\langle \rho^2 \right\rangle^2 + \frac{1}{N_c} f^{ab\kappa} f^{cd\kappa}\left\langle \rho^2 \right\rangle^2 + \cdots$$

$$f_{gaa'}f_{g'bb'}f_{gcc'}f_{g'dd'}\;\delta^{ac}\delta^{bd}\;\delta^{a'b'}\delta^{c'd'} = N_c^2(N_c^2-1)$$

$$f_{gaa'}f_{g'bb'}f_{gcc'}f_{g'dd'}\;\frac{1}{N_c}f^{ab\kappa}f^{cd\kappa}\;\delta^{a'c'}\delta^{b'd'} = N_c^2(N_c^2-1)$$

Projectile Target

[Note: independent/uncorrel. production

$$f_{gaa'}f_{g'bb'}f_{gcc'}f_{g'dd'}\;\delta^{ac}\delta^{bd}\;\delta^{a'c'}\delta^{b'd'} = N_c^2(N_c^2-1)^2$$

]

Summary:

- kinematic regime:

  $p,q \sim Q_s$ (say, 1-3 GeV for pp @ LHC, AA @ RHIC)
- effect disappears for small Q_s / large p,q
- $\Phi \ll \pi$

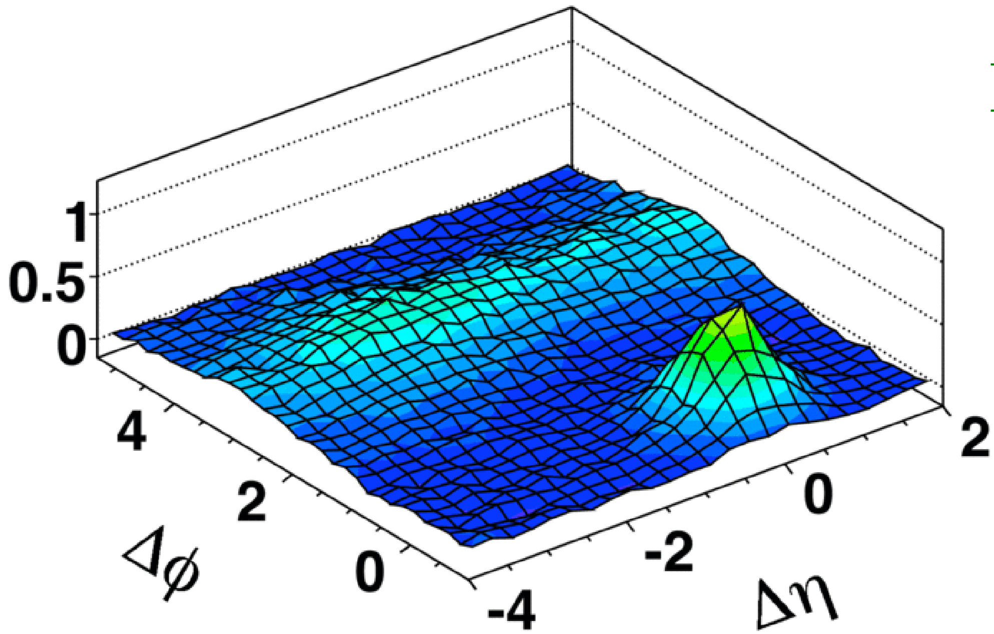
- particle correlations probe complete B-JIMWLK evolution equation incl. "N_c corrections"

  (unlike single-inclusive cross-section !)

- should be interesting for pp @ LHC

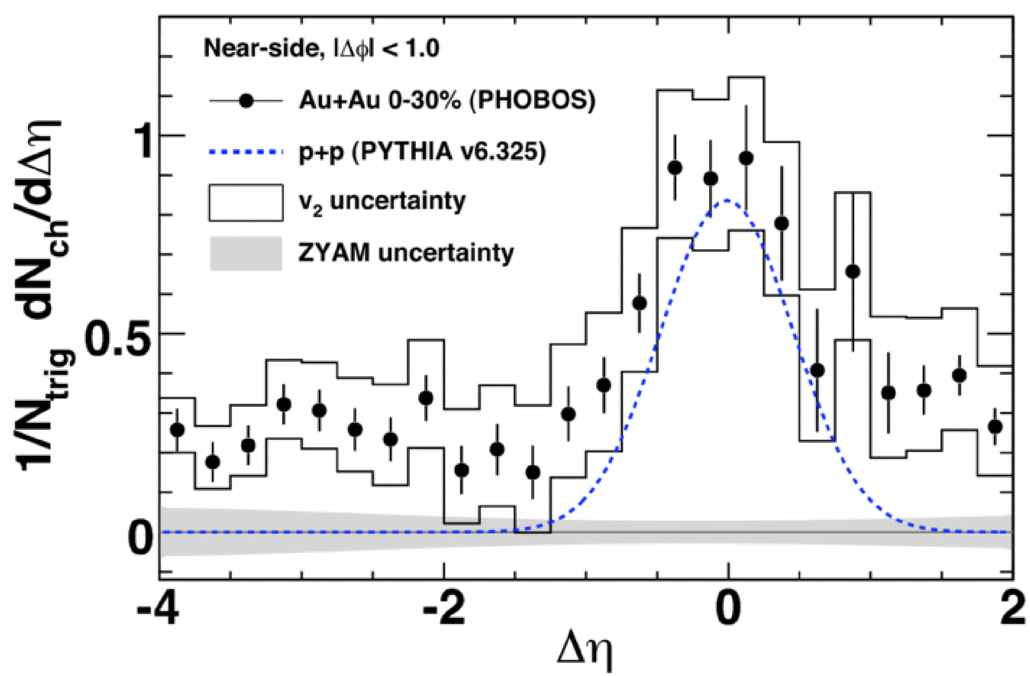
Backup Slides

PHOBOS (arXiv:0903.2811):



PYTHIA pp, p_T^{trig} > 2.5 GeV

PHOBOS Au+Au, 0-30%, p_T^{trig} > 2.5 GeV

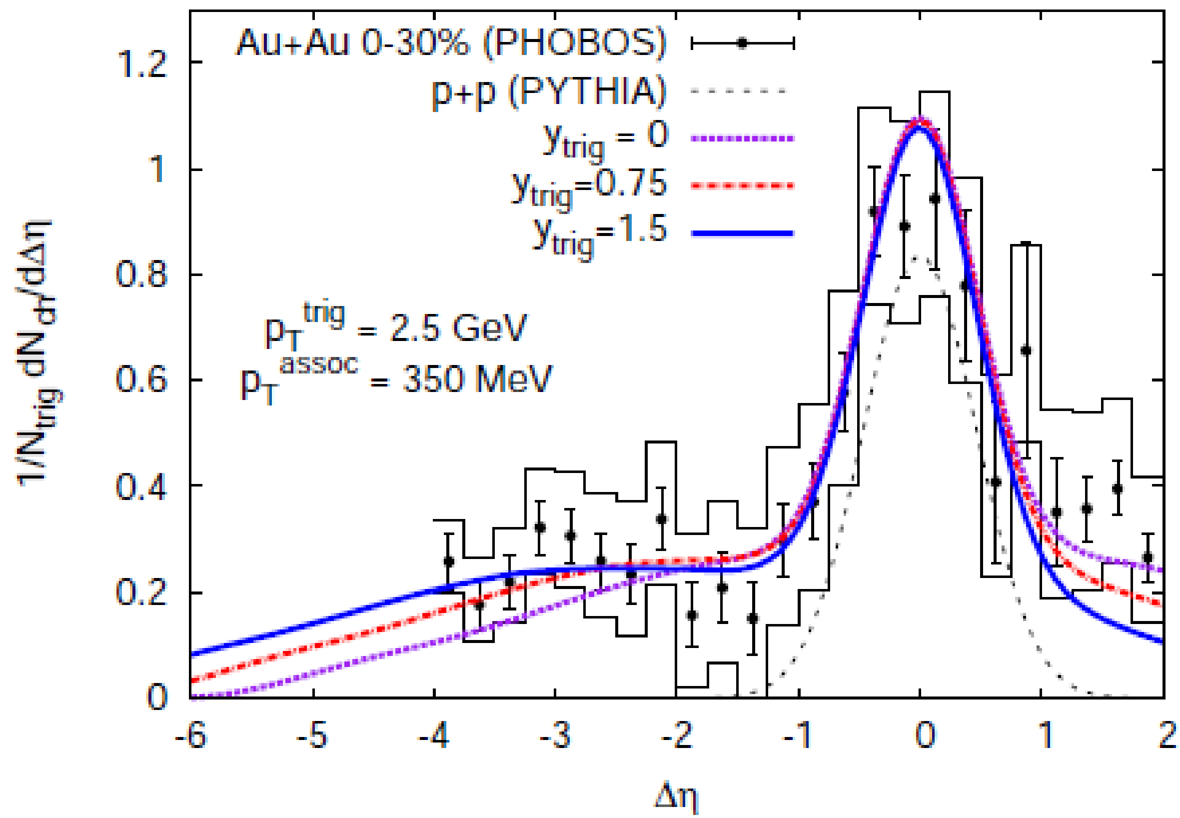


long-range rapidity evolution and small-x evolution

- finite width predicted
- *very* wide though,

hard to see at RHIC

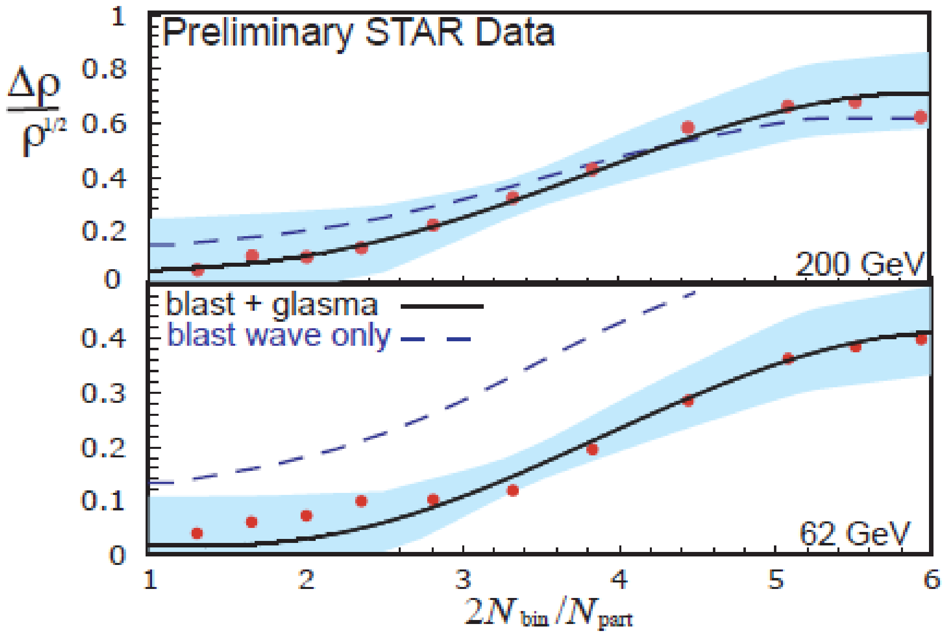
(need $\Delta\eta$~6 !)



Dusling, Gelis, Lappi, Venug.: 0911.2720

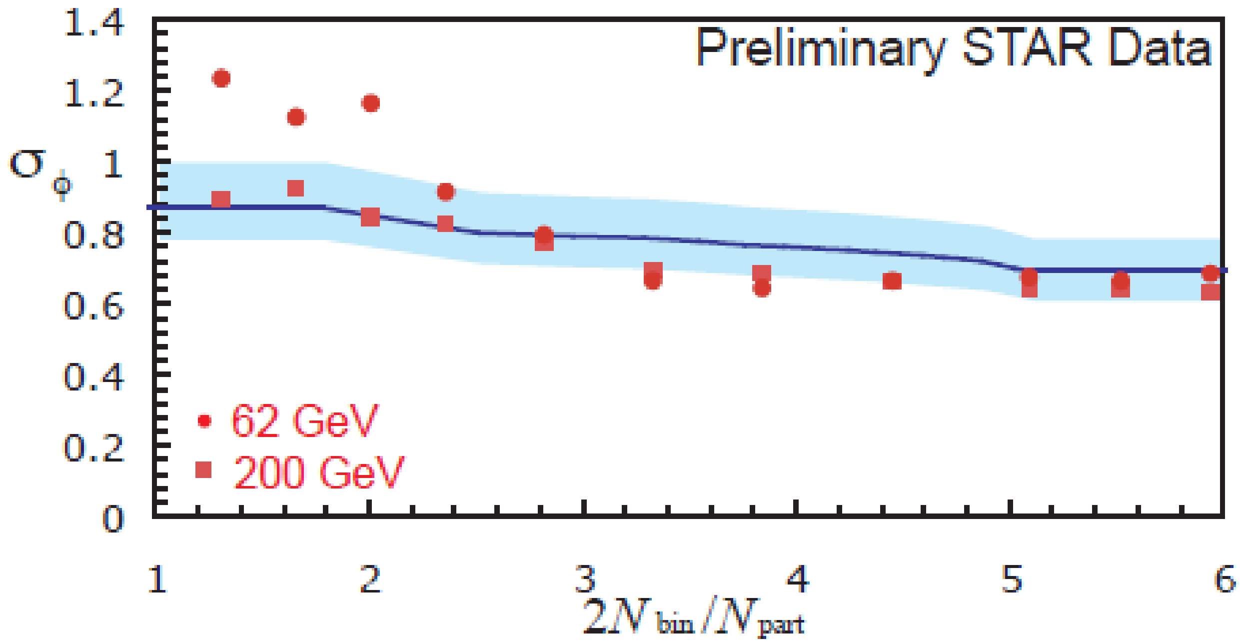
boost from radial flow

amplitude



centrality —>

azimuthal width



Gavin, McLerran, Moschelli: 0806.4718